The physics of black hole binaries: geodesic properties, quasinormal modes and interaction with fundamental fields

- Part II -

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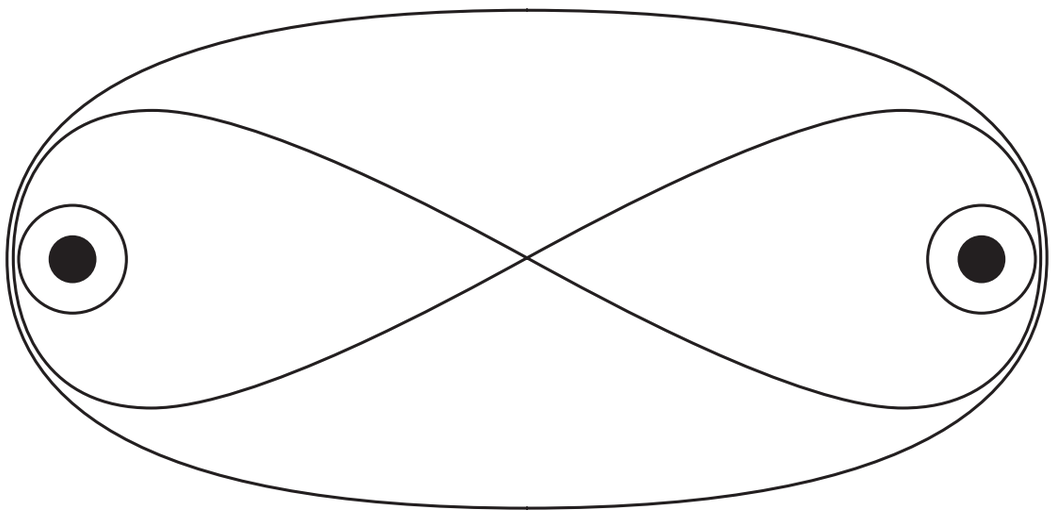
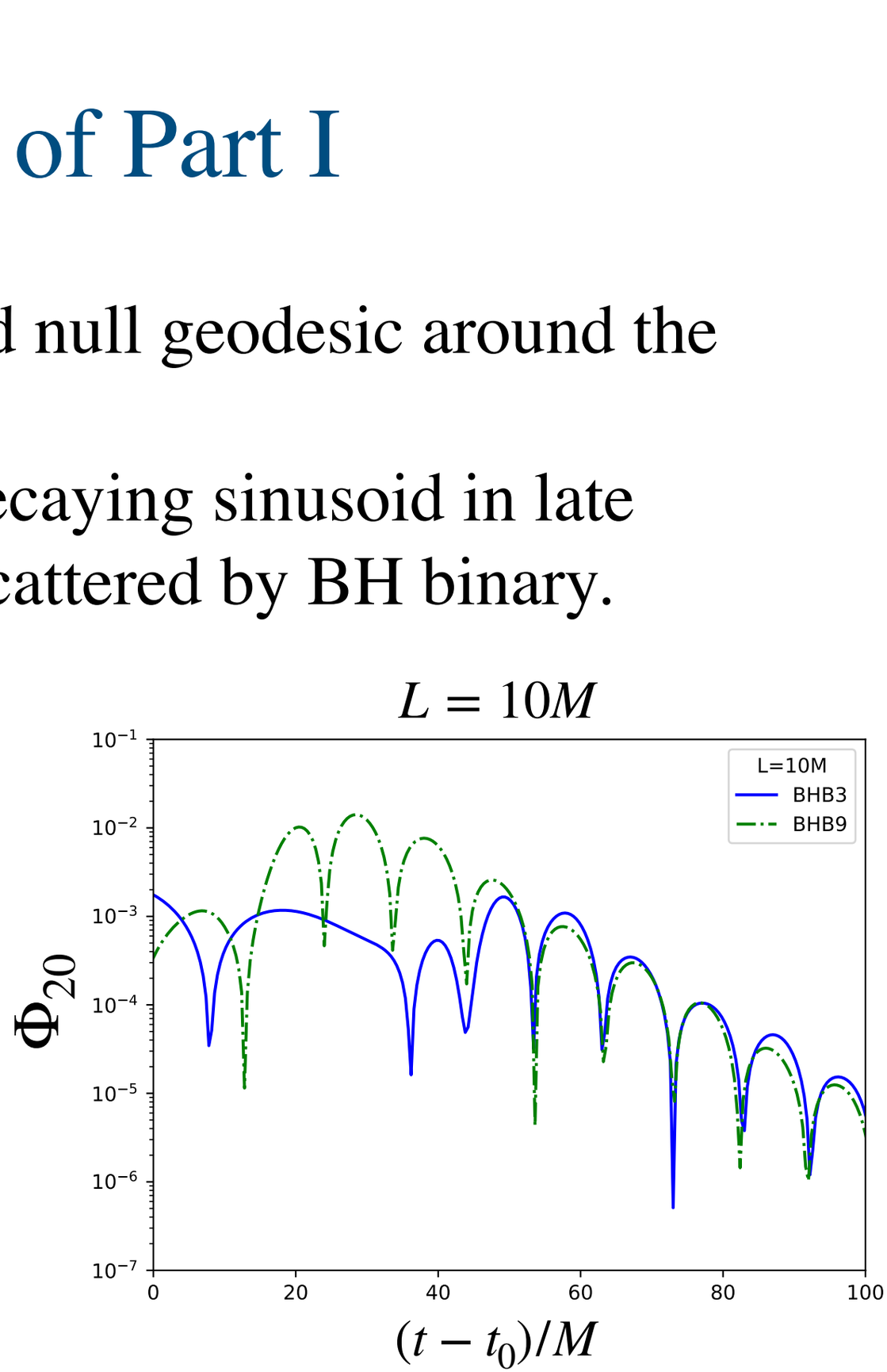
Summary of Part I

- We found the 3 types of closed null geodesic around the BH binary
- We found the exponentially decaying sinusoid in late time of massless scalar field scattered by BH binary.



a.s.c.



Contents

Further discussion of QNM

- Quasi-normal mode of BH spacetime

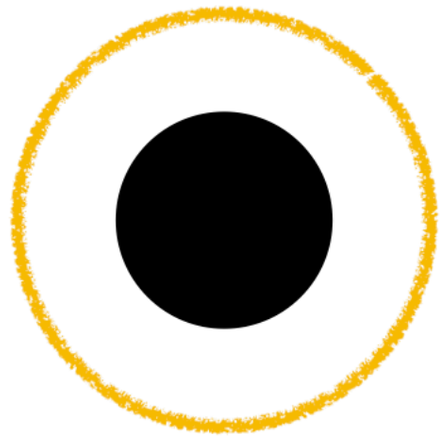
$$\Phi_{lm} \sim e^{i\omega_{\mathrm{QNM}}t}$$

$\mathrm{Re}(\omega_{\mathrm{QNM}})$: frequency of oscillation

$\mathrm{Im}(\omega_{\mathrm{QNM}})$: decay late of the mode

- Relation between QNM and closed null orbit around BH (based on WKB approximation)

$$\omega_{\mathrm{QNM}} = \Omega_{\mathrm{c}} l - i\left(n + \frac{1}{2}\right)|\lambda|$$



Ω_{c} : angular velocity at the unstable closed orbit

l : angular momentum of perturbation

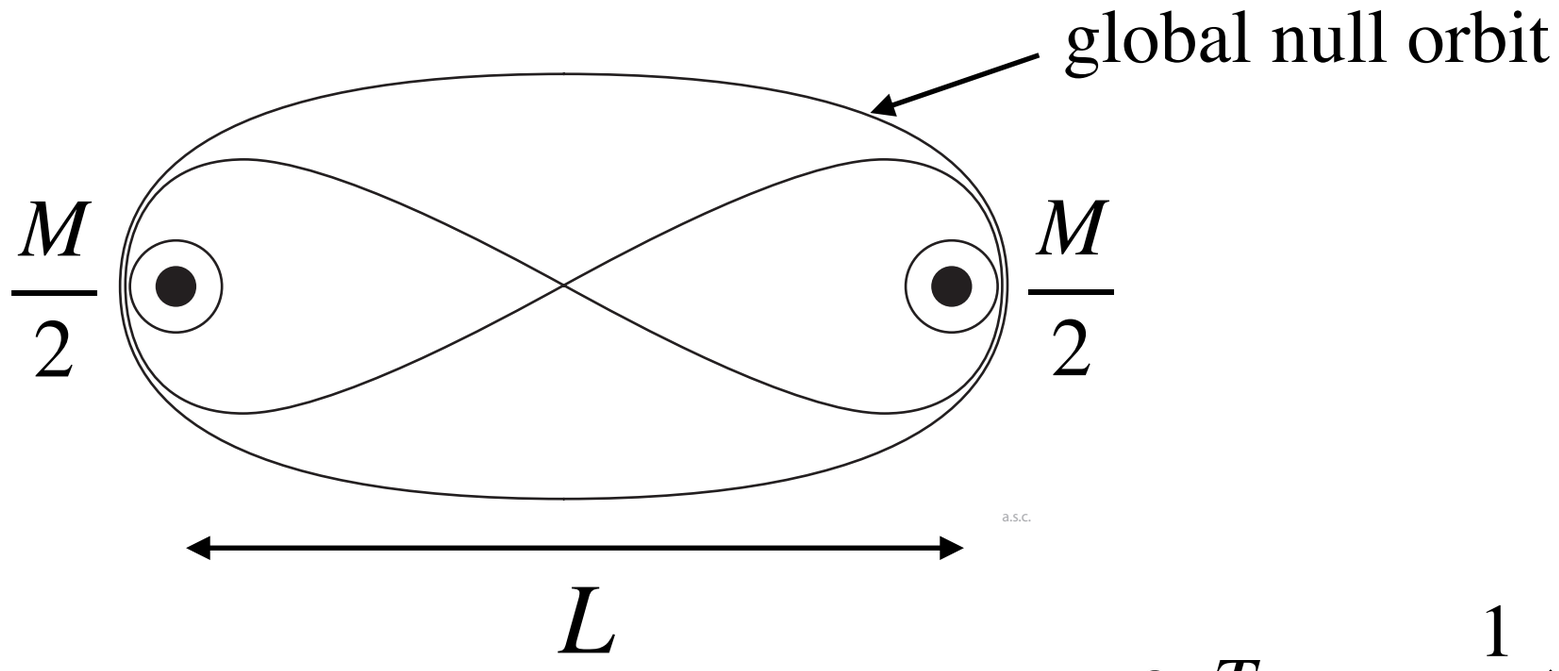
n : overtone number

λ : Lyapunov exponent

- Period of QNM : $T_{\mathrm{QNM}} = \dfrac{1}{l} \times \dfrac{2\pi}{\Omega_{\mathrm{c}}}$

Further discussion of QNM

- We apply this formula to global null orbit.



cf: $T_{\mathrm{QNM}} = \dfrac{1}{l} \times \dfrac{2\pi}{\Omega_{\mathrm{c}}}$

- Estimation of the period for $l = 2$ mode

$$T_{\mathrm{QNM}} \simeq \frac{1}{2}\left(2L + T_{\mathrm{LR}}\right) \simeq L + 8M$$

where

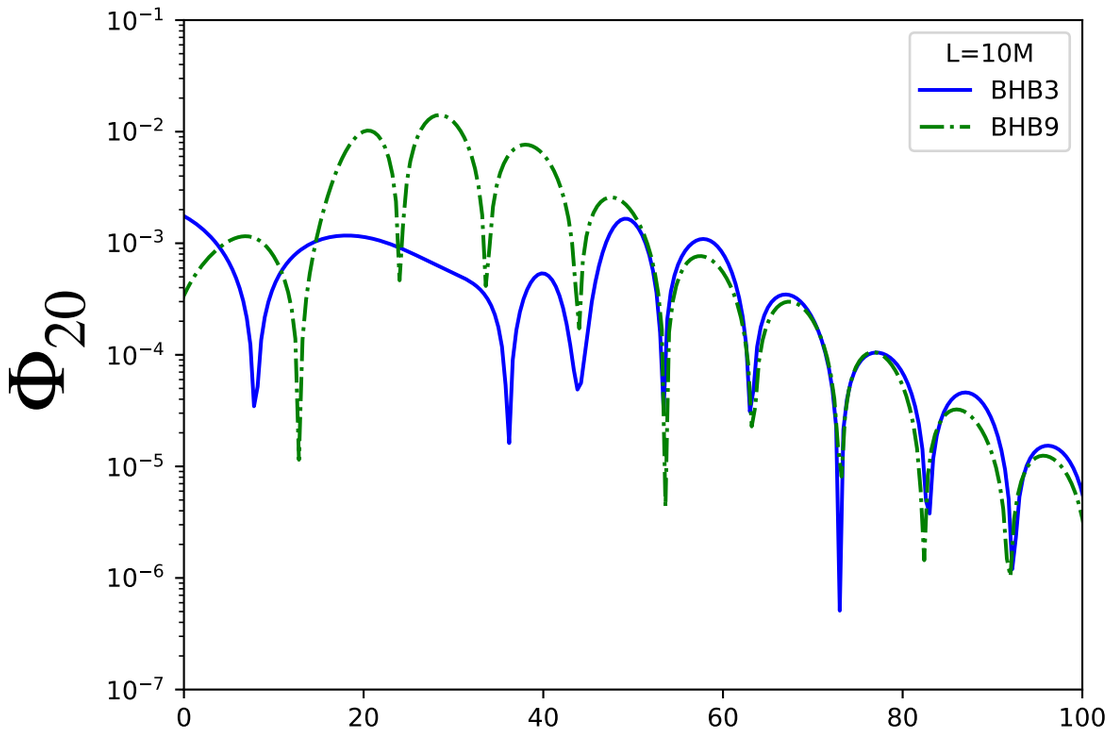
$$T_{\mathrm{LR}} = 6\sqrt{3}\frac{M}{2} \simeq 16.3M$$

Further discussion of QNM

- The period of late time exponentially decaying sinusoid agree with expectation.

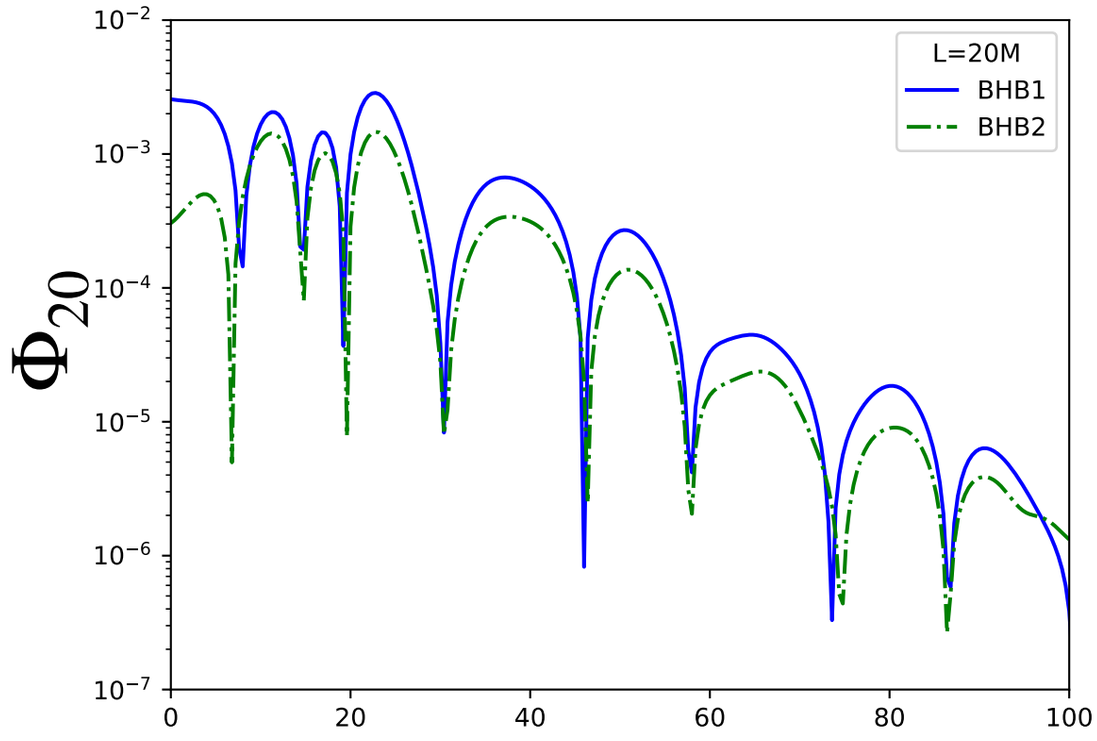
cf: $T_{\mathrm{QNM}} \simeq L + 8M$

$L = 10M$



$T \simeq 18M$

$L = 20M$



$T \simeq 28M$

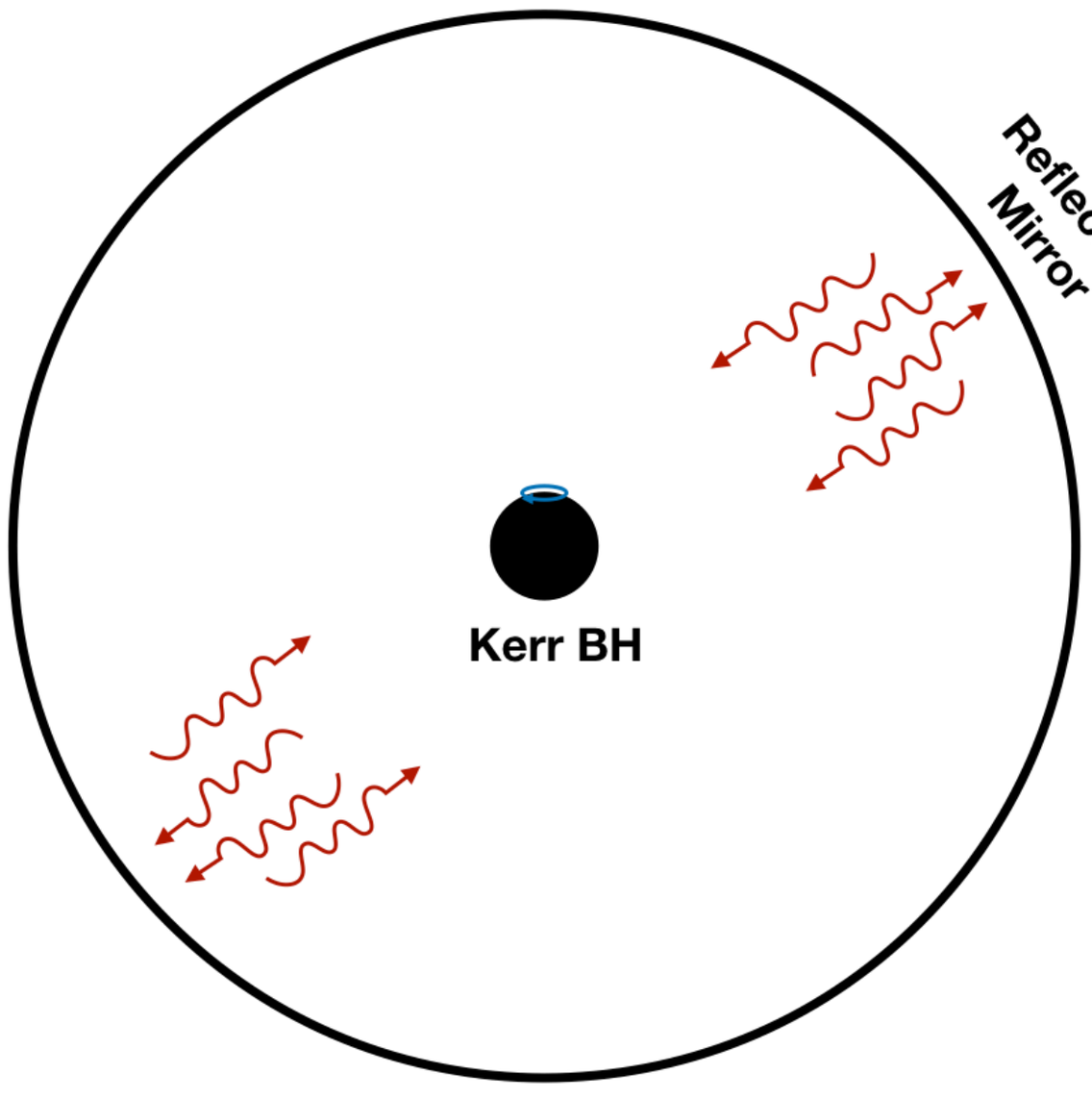
This is global QNM which corresponds to global closed null geodesic.

Contents

Energy extraction

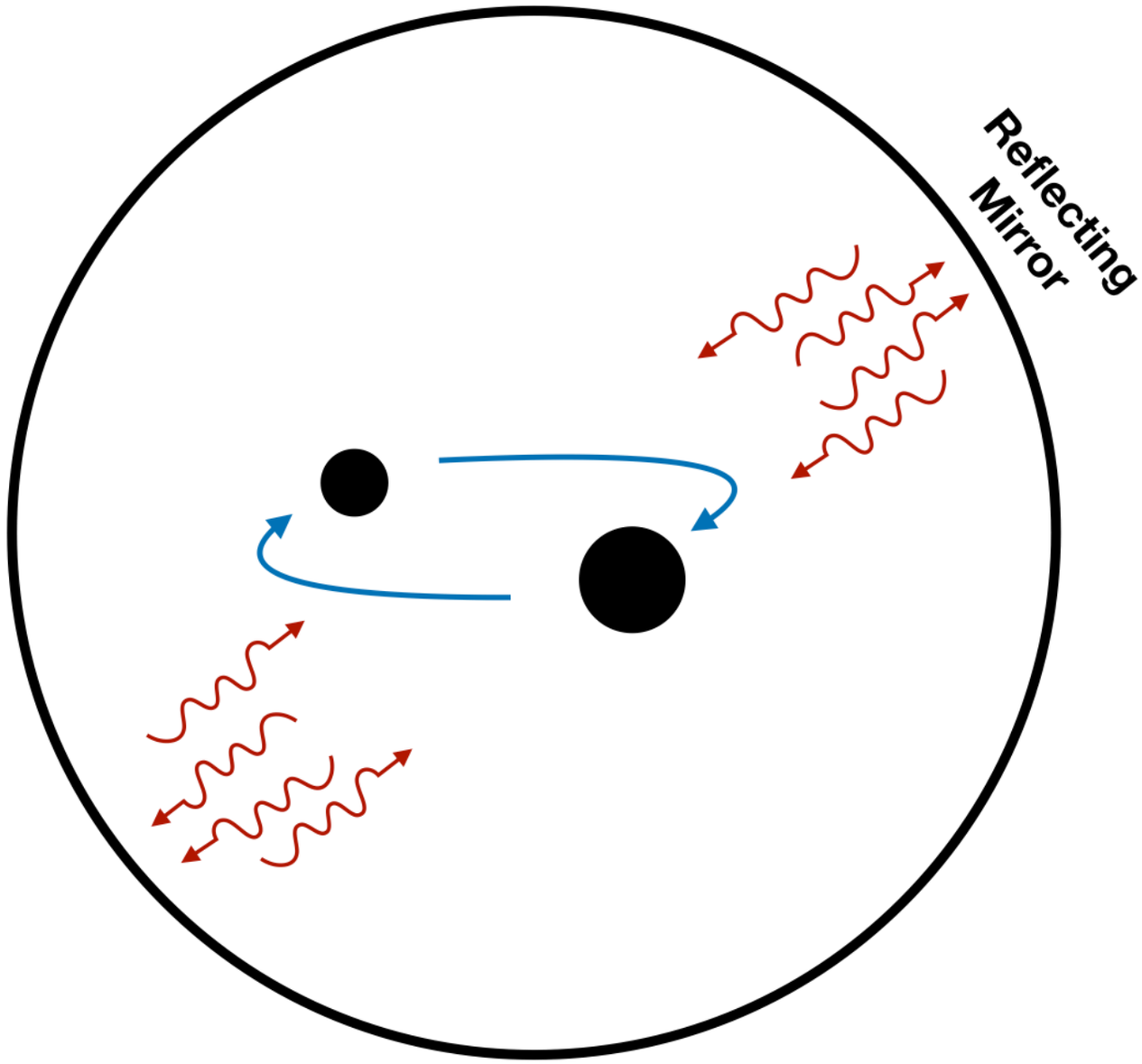
Black hole bomb

cf: super-radiant instability



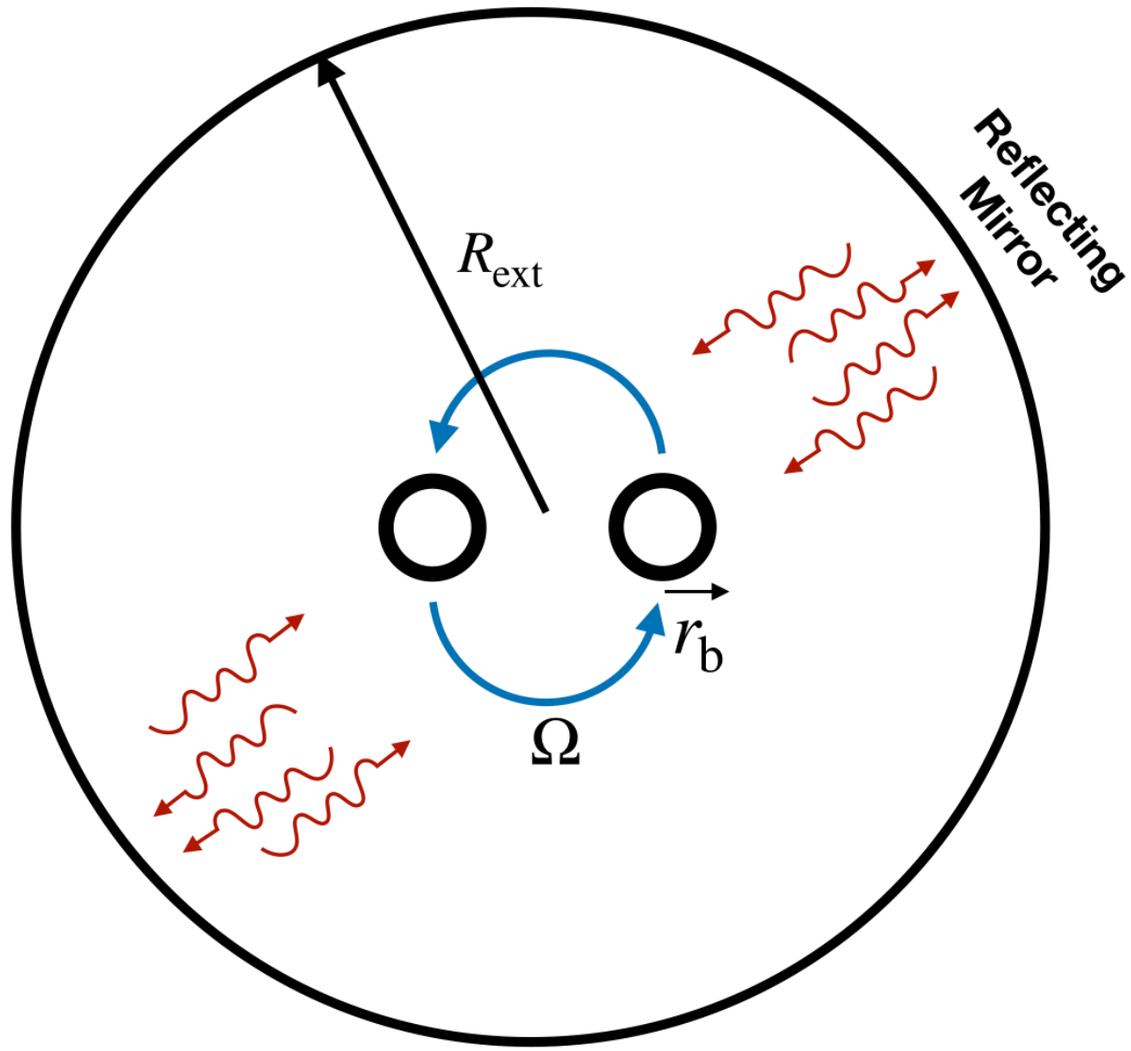
Energy extraction

- Question
  - Can we realize the BH binary bomb ?



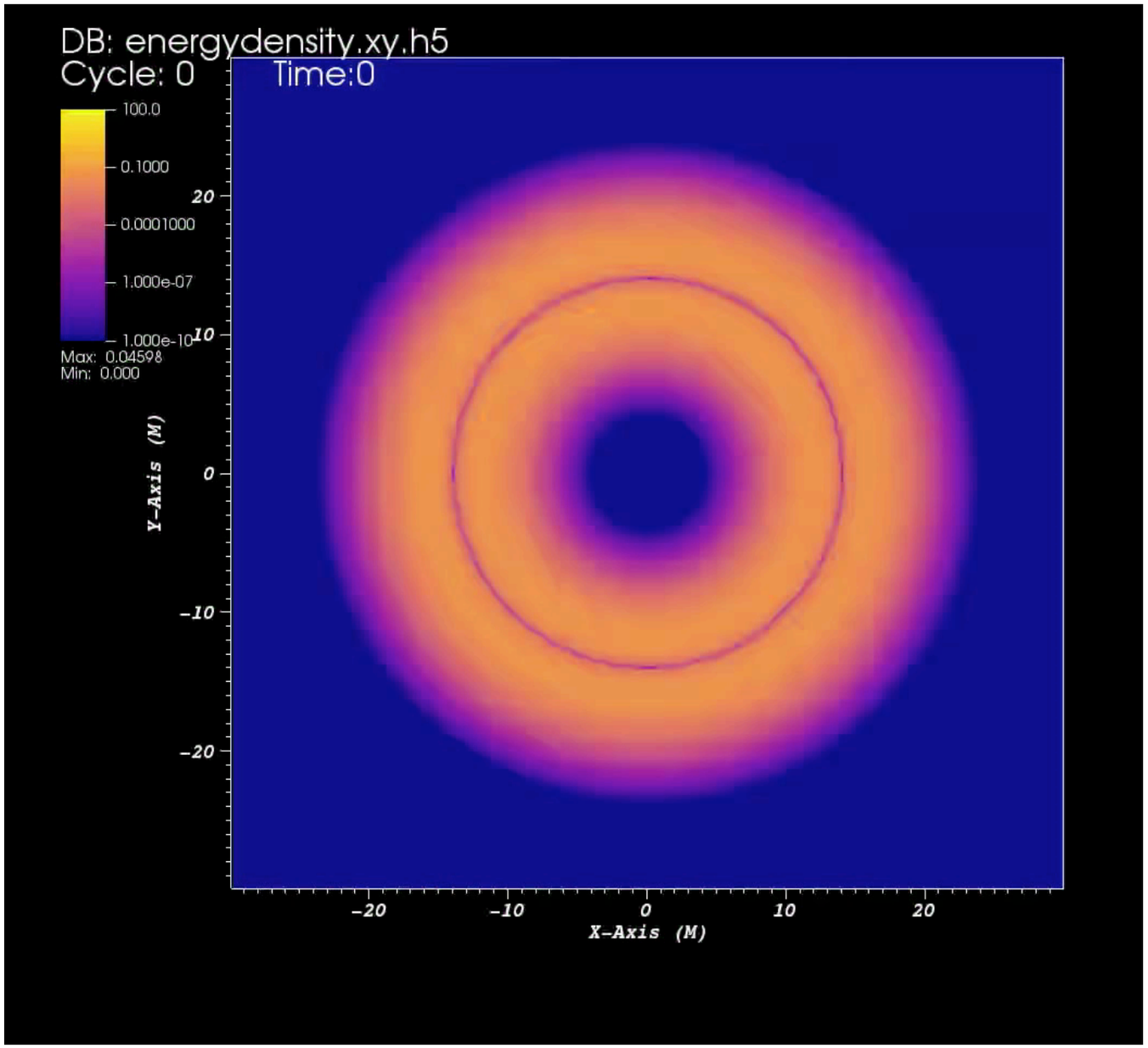
Energy extraction

- Probably, the time scale of BH binary bomb is very long.
- As a toy mode, we consider a confined scalar field around two rotating reflecting ball in 2+1 dim flat spacetime.

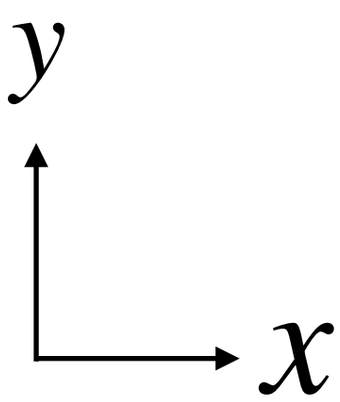


Energy extraction

Energy density

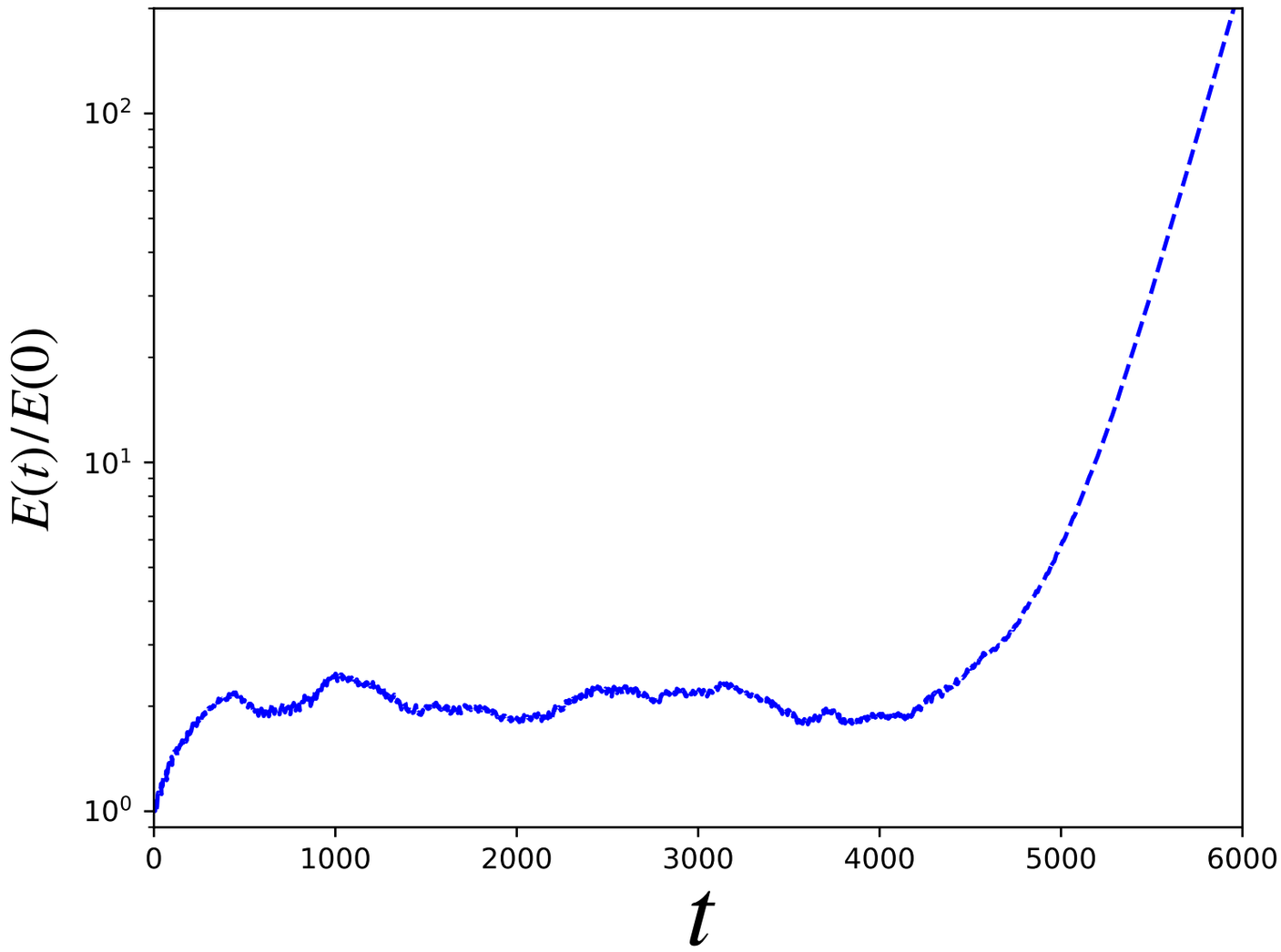


$R_{\rm ext} = 30,\ \Omega = 0.14,\ r_{\rm b} = 0.5$



Energy extraction

- The energy of the scalar field grows exponentially.

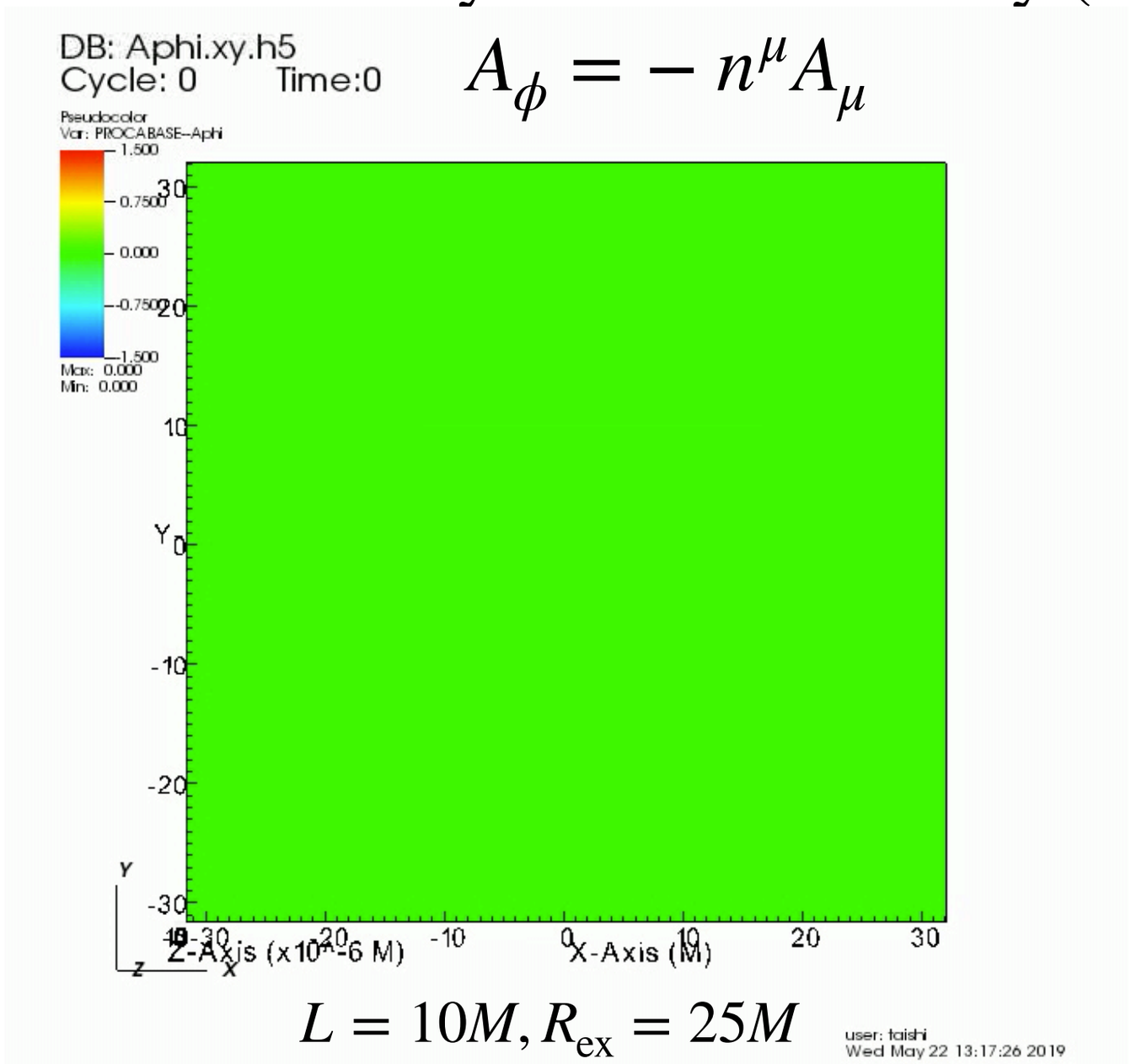


$R_{\mathrm{ext}} = 30,\ \Omega = 0.14,\ r_{\mathrm{b}} = 0.5$

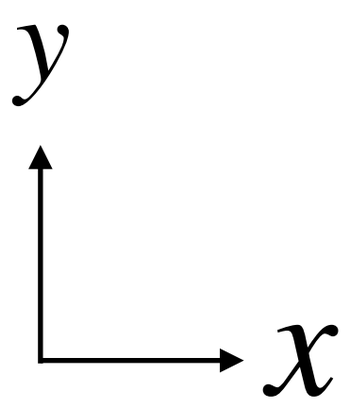
Energy extraction

- Preliminary result
  - Vector field inside cavity around BH binary (3+1 dim)

$$A_\phi = -n^\mu A_\mu$$



$$L = 10M, R_{\rm ex} = 25M$$



Energy extraction

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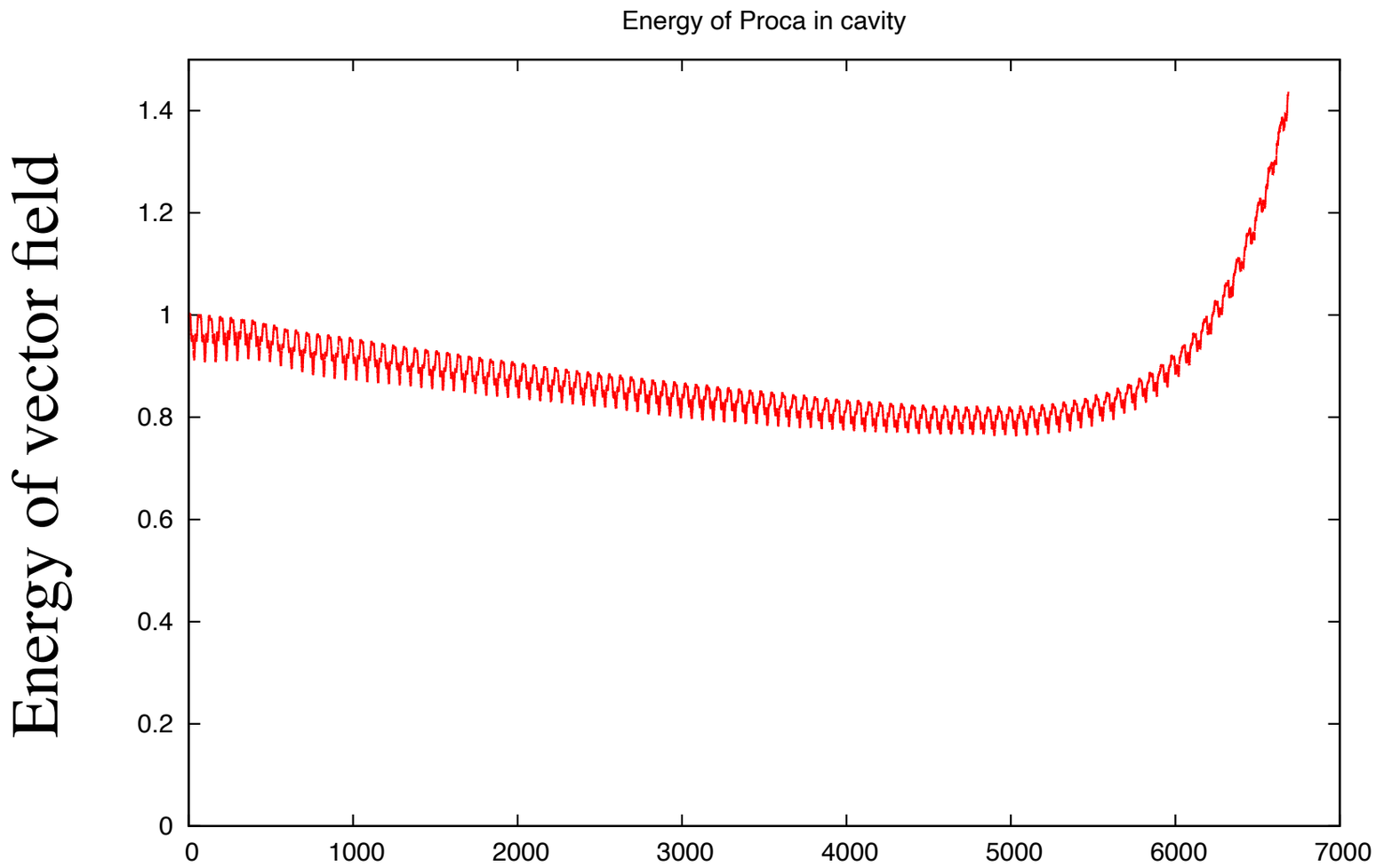


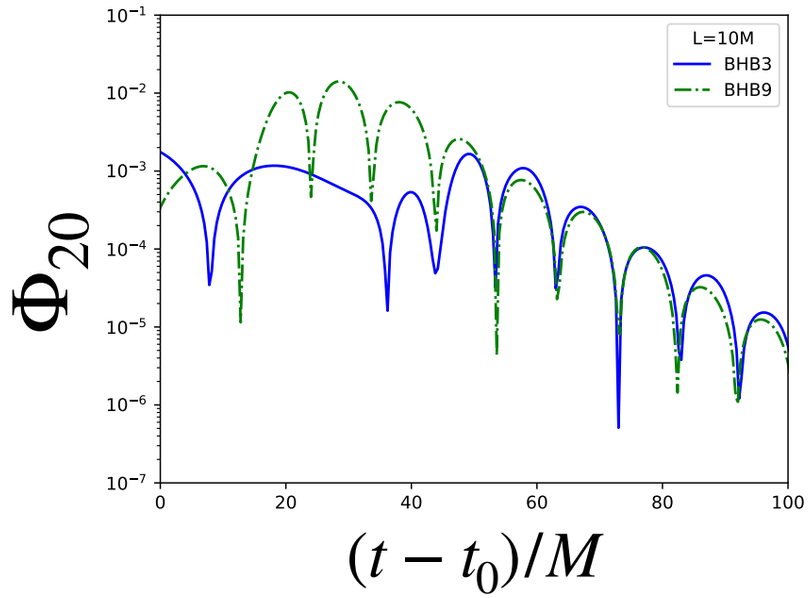
$L = 10M, R_{\rm ex} = 25M$

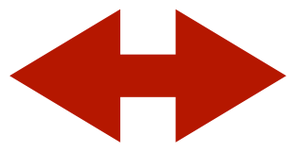
Energy grows !!

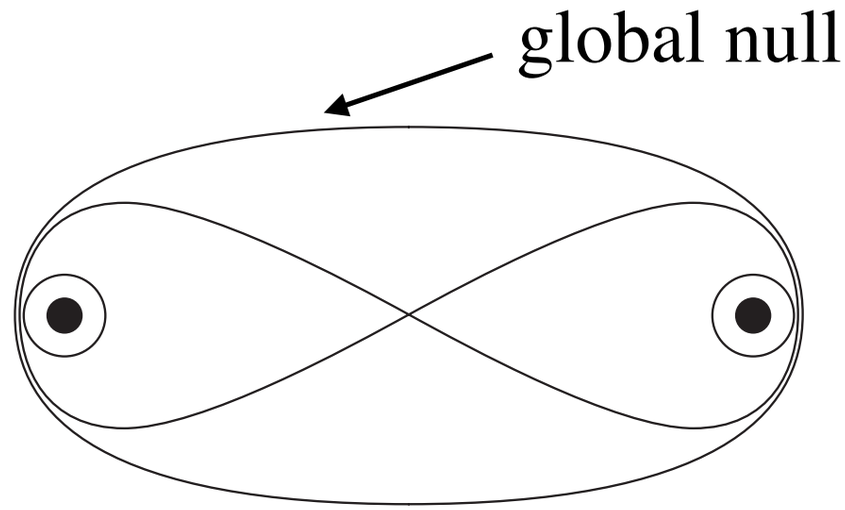
Contents

Summary

- We found
  - global QNM in BH binary spacetime.







  - the energy extraction of confined scalar field around the two rotating reflecting ball in 2+1 dim flat spacetime.
- Future work
  - BH binary bomb of scalar field and vector field in 3+1 dim spacetime (more detailed analysis).

Thank you !!